

NEW RESONANCES AND MESON SPECTROSCOPY



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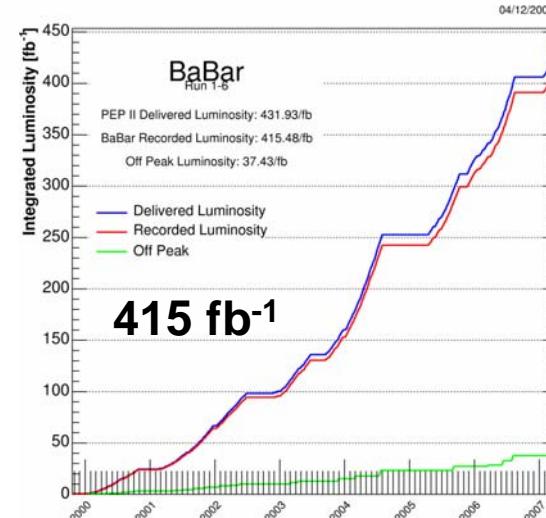
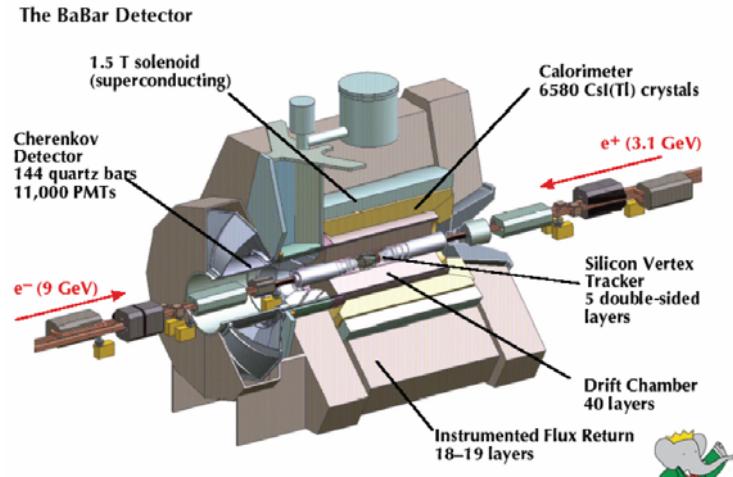
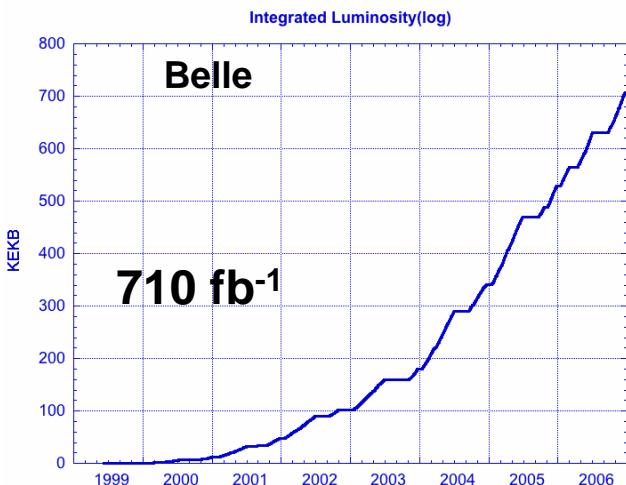
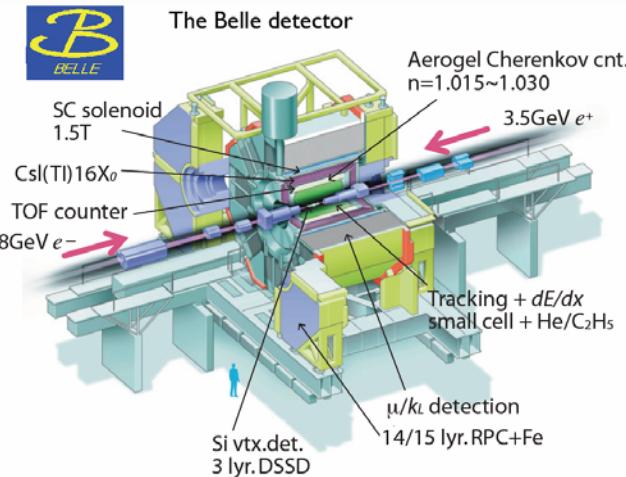
On behalf of the Belle and BaBar collaborations

NEW RESONANCES: OVERVIEW

- $c\bar{s}$ mesons
 - $D_{s0}^*(2317)$ and $D_{s1}(2460)$: surprising states
 - $D_{sJ}^*(2860)$: another new state
 - $X(2690)$ and $D_{sJ}(2700)$: even more new states, or are they the same state?
- $c\bar{c}$ mesons (charmonium(-like) states)
 - $X(3940)$, $Y(3940)$ and $Z(3930)$: real charmonium states?
 - $X(3872)$: a continuing mystery
 - $Y(4260)$: one more mystery!
- Other resonances not covered here
 - Light meson resonances
 - Baryons

BELLE AND BABAR: B AND c-FACTORIES

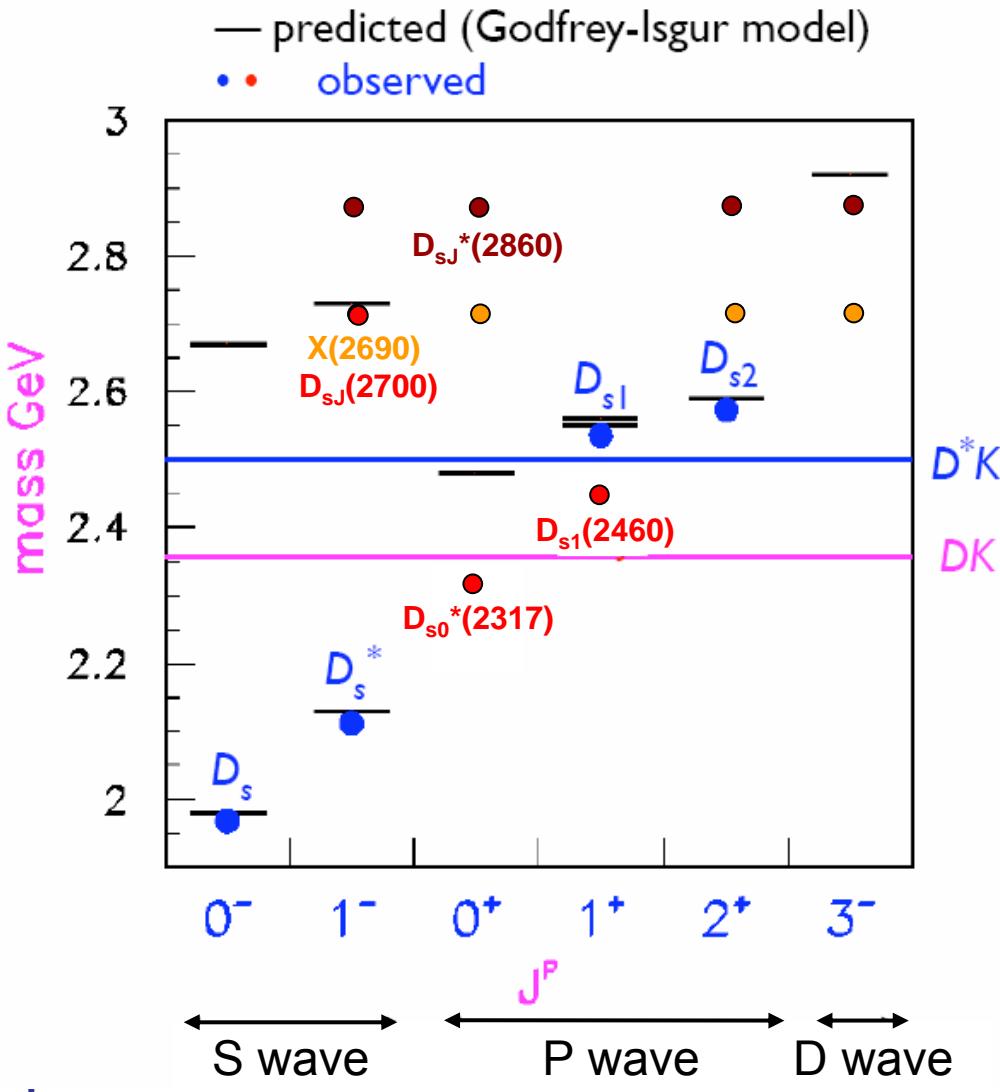
Asymmetric e^+e^- collisions at 10.58 GeV



c \bar{s} MESONS

WHAT IS NEW FOR D_{sJ} STATES?

CURRENT SITUATION



- $D_{s0}^*(2317)^+$, Apr. 2003: unexpected observation of a narrow resonance in **BaBar**
- $D_{s1}(2460)^+$, May 2003: **CLEO**, **BaBar** observed a new narrow resonance
- $D_{sJ}^*(2860)^+$, Jul. 2006: new state discovered by **BaBar**
- $X(2690)^+$, Jul. 2006: broad enhancement seen in **BaBar**
- $D_{sJ}(2700)^+$, Jul. 2006: new state discovered by **Belle** ($\equiv X(2690)$?)

Let's go step by step!

$D_{s0}^*(2317)$ AND $D_{s1}(2460)$ UPDATE

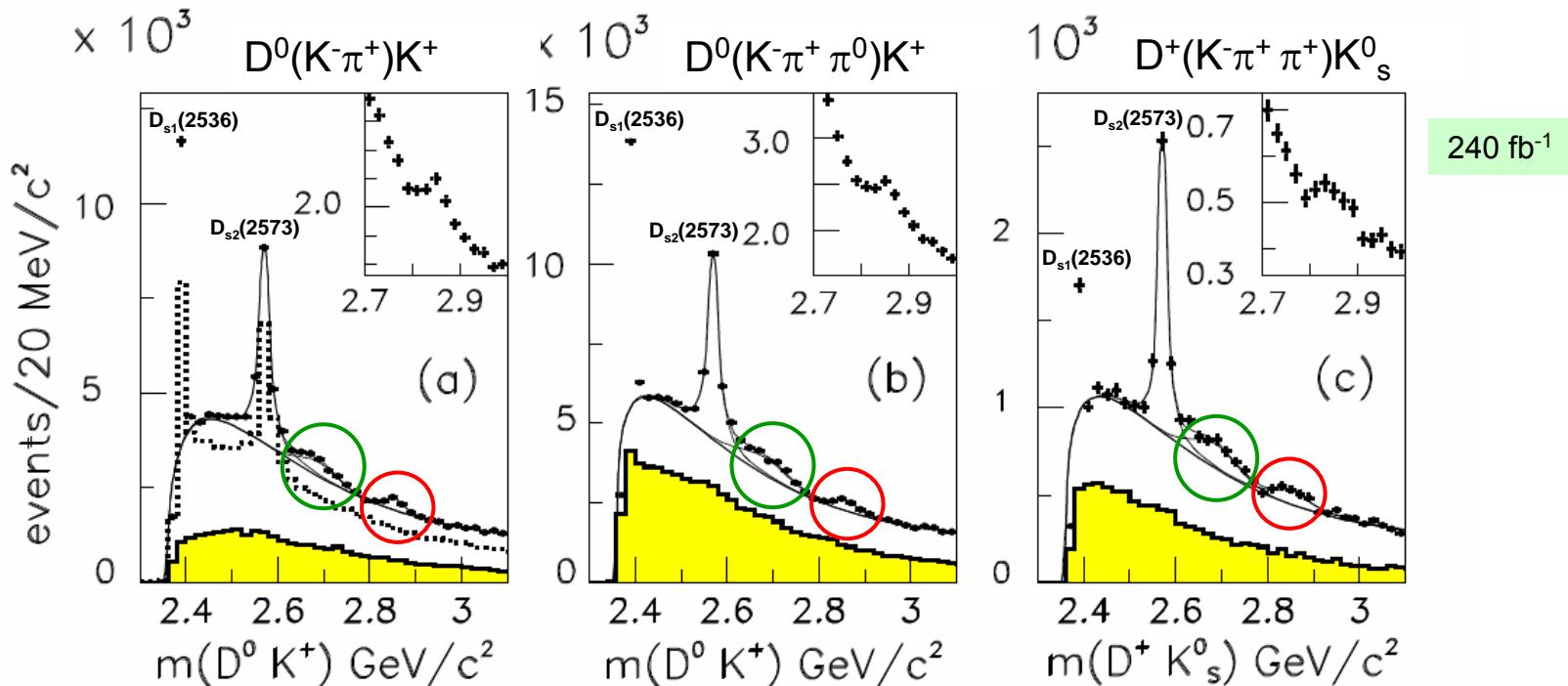
- Discovered 4 years ago in $e^+e^- \rightarrow c\bar{c}$ events, observed in B decays
- $D_{s0}^*(2317)$ and $D_{s1}(2460)$ very well established and known experimentally
 - Masses and widths
 - Natural J^P : 0^+ for $D_{s0}^*(2317)$ and 1^+ for $D_{s1}(2460)$
 - decay modes and branching fractions
- Interpretation of these new states still unclear!
 - One possibility: identify these 2 states as the **0^+ and 1^+ $c\bar{s}$ states**
 - However strong difficulties within the potential model
 - Other possibilities
 - 4 quark states? DK molecule? $D\pi$ atom? Chiral symmetry?
- Are there some more surprises? Yes!

Belle: Phys. Rev. Lett. 91 (2003) 262001
BaBar: Phys. Rev. D74 (2006) 032007
Belle: Belle-Conf-0461 (2006)
BaBar: Phys. Rev. D74 (2006) 031103

$D_{sJ}^*(2860)$: ANOTHER NEW STATE



- Looking in the $c\bar{c}$ continuum: $e^+e^- \rightarrow D^0(K^-\pi^+, K^-\pi^+\pi^0)K^+X$ and $e^+e^- \rightarrow D^+(K^-\pi^+\pi^+)K^0_sX$



- ○ New state at $2860 \text{ MeV}/c^2$!
- ○ Bump at $2690 \text{ MeV}/c^2$?

$D_{sJ}^*(2860)$ AND... $X(2690)$?



- Combining the 3 modes

- $M = (2856.6 \pm 1.5 \pm 5.0) \text{ MeV}/c^2$
- $\Gamma = (47 \pm 7 \pm 10) \text{ MeV}$
- $J^P = 0^+, 1^-, 2^+, \dots$
 - Final state is DK, i.e. two pseudoscalars

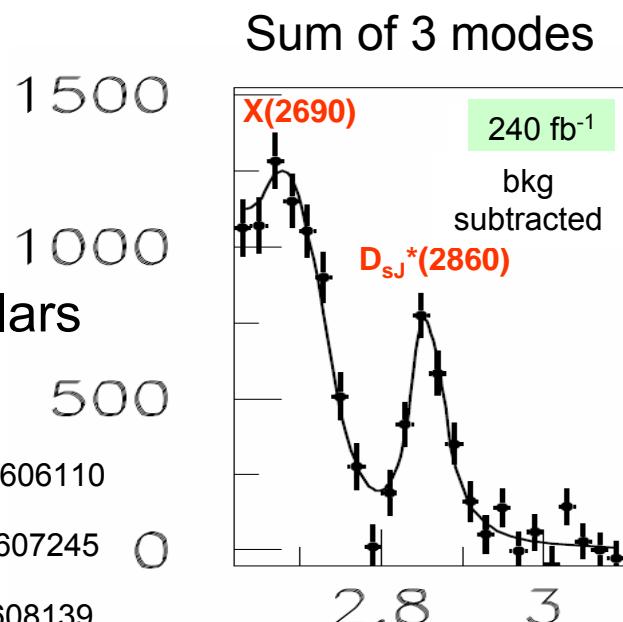
- Interpretation?

- Radial excitation of $D_{s0}^*(2317)$? hep-ph/0606110
- $c\bar{s}$ with $J^P = 3^-$? hep-ph/0607245
- $c\bar{s}$ with $J^P = 0^+$? hep-ph/0608139

- Another structure at 2690 MeV/c^2 ?

- $M = (2688 \pm 4 \pm 3) \text{ MeV}/c^2$
- $\Gamma = (112 \pm 7 \pm 36) \text{ MeV}$

- Need confirmation by other experiments...

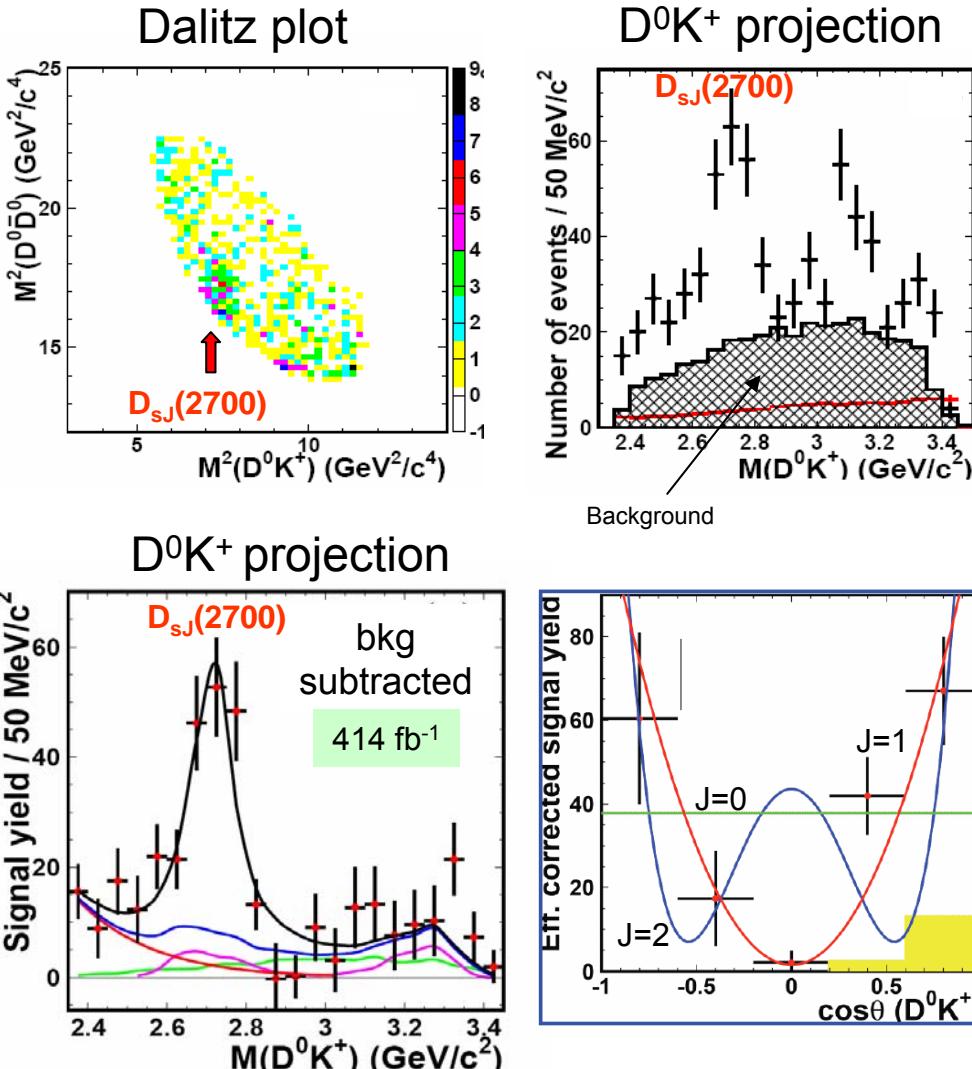


EVEN MORE STATES: D_{SJ}(2700)



- Study of $B^+ \rightarrow \bar{D}^0 D^0 K^+$
 - Looking at the **Dalitz plot** and the $D^0 K^+$ projection
- New resonance decaying to $D^0 K^+$
 - $B^+ \rightarrow \bar{D}^0 D_{SJ}$, $D_{SJ} \rightarrow D^0 K^+$
 - $M = (2715 \pm 11^{+11}_{-14}) \text{ MeV}/c^2$
 - $\Gamma = (115 \pm 20^{+36}_{-32}) \text{ MeV}$
 - $J^P = 1^-$ favored
- Same resonance as seen by BaBar in continuum, $X(2690)$?
 - Mass and width consistent, same decay mode
- Interpretation?
 - $c\bar{s}$ state 2^3S_1 ?
 - expected mass at 2720 MeV/c^2
 - **Chiral symmetry:** $1^+ - 1^-$ doublet paired with $D_{s1}(2536)$?

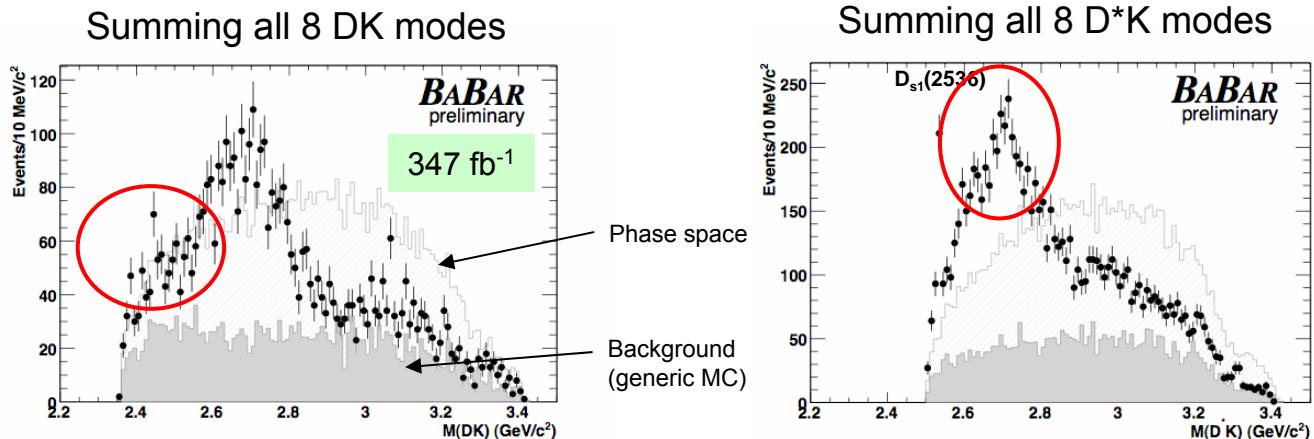
Phys.Polon. B 35, 2377 (2004)



EVEN MORE STATES: $D_{sJ}(2700)$



- Study of $B \rightarrow \bar{D}^{(*)} D^{(*)} K$ decays in BaBar (22 modes)
 - Looking at 8 DK + 8 D^*K invariant masses, adding **15 decay modes** wrt Belle



New result
preliminary

- Enhancement observed around 2700 MeV/c² in DK and D^*K
- Additional c \bar{s} surprise? Maybe!
 - Low mass enhancement in DK ?
 - Belle sees it and uses an exponential
 - One or two resonances around 2.6-2.7 GeV/c² in D^*K ?
- Need to perform a full Dalitz plot analysis
 - Takes into account **interferences**

c \bar{c} MESONS CHARMONIUM-(LIKE) STATES

LOTS OF UNEXPECTED DISCOVERIES

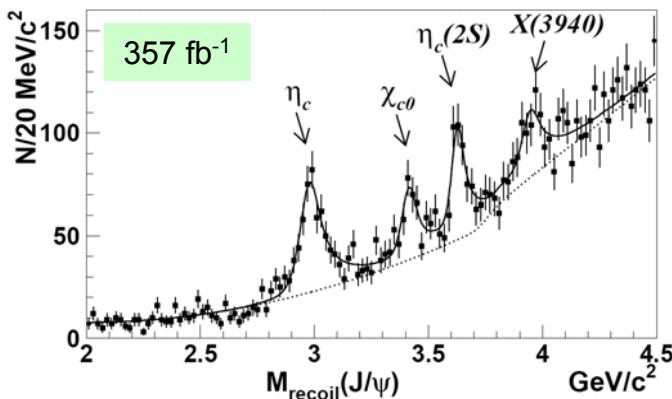
- X(3940), Y(3940) and Z(3930)
- X(3872)
- Y(4260)

X(3940), Y(3940) AND Z(3930)



X(3940)

New state seen in $e^+e^- \rightarrow J/\psi X$

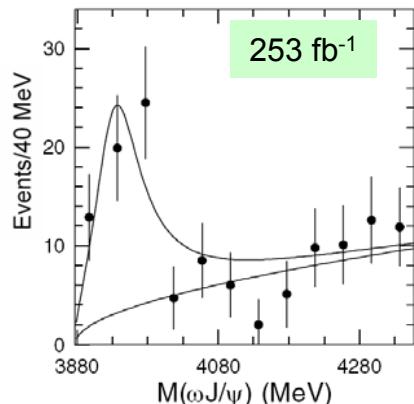


Also, observed $X \rightarrow \bar{D}D^*$,
but not $X \rightarrow \bar{D}D$

$M = (3943 \pm 6 \pm 6) \text{ MeV}/c^2$
 $\Gamma = (15.4 \pm 10.1) \text{ MeV}$
 $c\bar{c}$ state $\eta_c(3S)$ [3¹S₀]?

Y(3940)

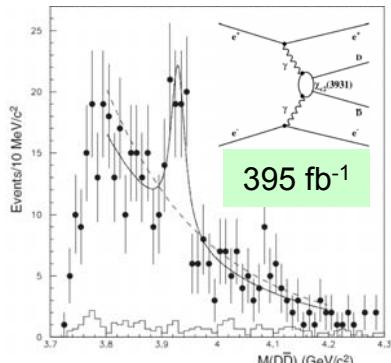
Near threshold enhancement in $B \rightarrow J/\psi \omega K$



$M = (3943 \pm 11 \pm 13) \text{ MeV}/c^2$
 $\Gamma = (87 \pm 22 \pm 26) \text{ MeV}$
 $c\bar{c}$ state χ'_{c1} [2³P₁]?

Z(3930)

New resonance state in $\gamma\gamma \rightarrow \bar{D}D$



$M = (3929 \pm 5 \pm 2) \text{ MeV}/c^2$
 $\Gamma = (29 \pm 10 \pm 2) \text{ MeV}$
 $c\bar{c}$ state χ'_{c2} [2³P₂]?

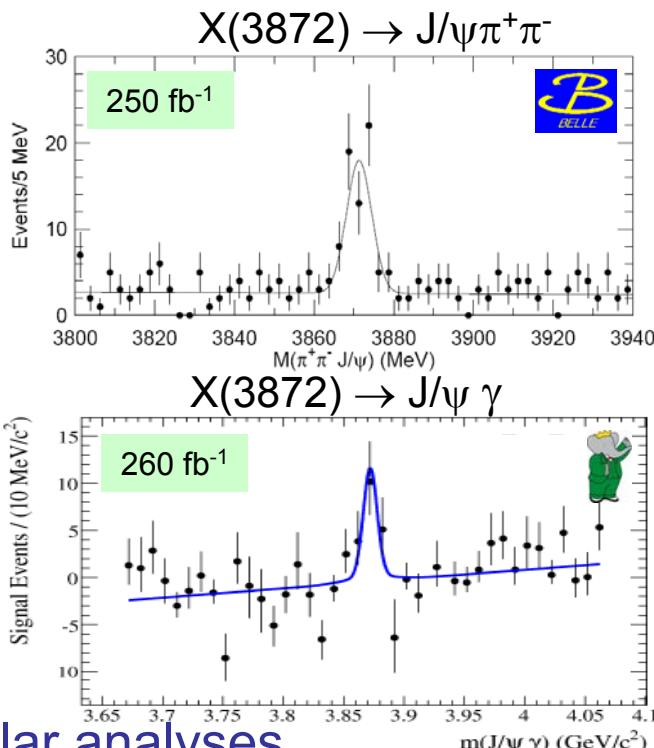
Belle: hep-ex/0507019

Belle: Phys. Rev. Lett. 94 (2005) 182002

Belle: Phys. Rev. Lett. 96 (2006) 082003

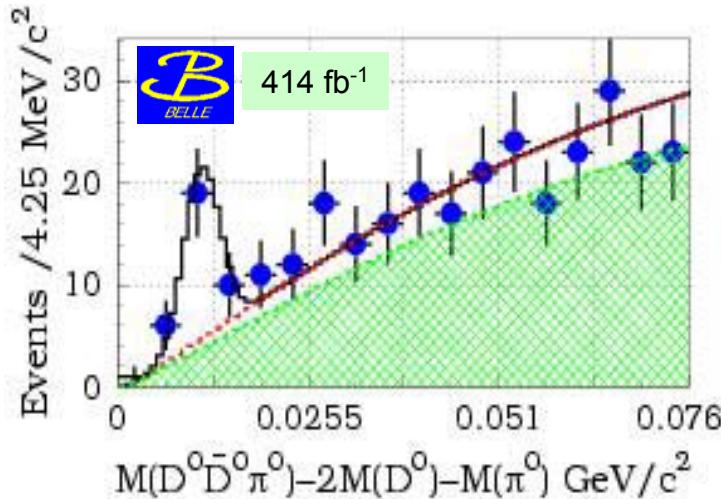
X(3872)

- First observation by **BELLE** in B decays:
 $B^\pm \rightarrow X(3872)K^\pm$ with $X(3872) \rightarrow J/\psi\pi^+\pi^-$
 - Confirmed by **BaBar**, **CDF**, **D0**
 - $M = (3871.2 \pm 0.5) \text{ MeV}/c^2$
 - $\Gamma < 2.3 \text{ MeV}$ at 90% CL
- Observation of $B \rightarrow X(3872)K$,
 $X(3872) \rightarrow J/\psi\gamma$
 - Implies: $C_{X(3872)} = +1$
- Belle, CDF: $\pi^+\pi^-$ inv. mass distribution + angular analyses
 - $L(\pi^+\pi^-) = \text{odd}$, $I = 1 \Rightarrow J/\psi\pi^0\pi^0$ should not be observed
 - $J^{PC} = 1^{++}$ favored
- BaBar: search for a charged partner (decaying to $J/\psi\pi^0\pi^-$)
 - **No signal** $\Rightarrow I = 0 \Rightarrow I$ violated in $J/\psi\pi^+\pi^-$



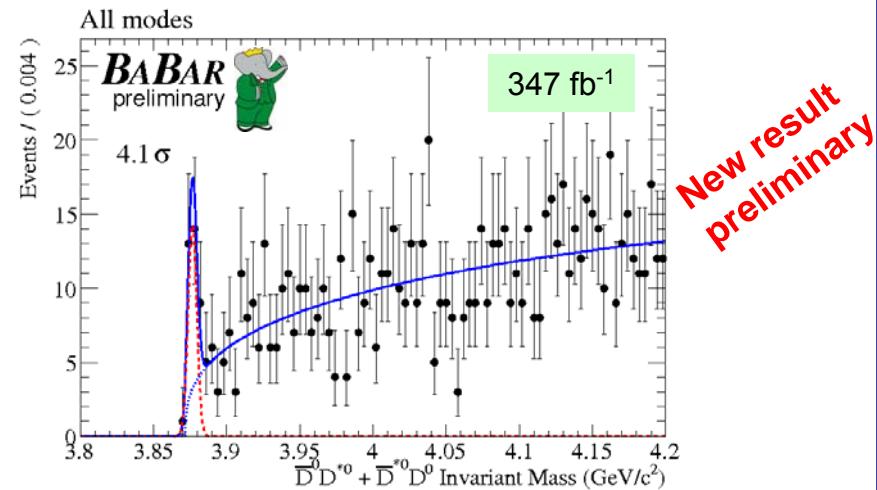
X(3872): STILL SOME SURPRISES

- Belle: looking at $B \rightarrow \bar{D}^0 D^0 \pi^0 K$



- Excess in the $\bar{D}^0 D^0 \pi^0$ invariant mass
 - $M = 3875.4 \pm 0.7^{+1.2}_{-2.0} \text{ MeV}/c^2$

- BaBar: looking at $B \rightarrow \bar{D}^0 D^{*0} K$ ($D^{*0} \rightarrow D^0 \pi^0/\gamma$)



- Excess in the $\bar{D}^0 D^{*0}$ invariant mass
 - $M = 3875.6 \pm 0.7^{+1.4}_{-1.5} \text{ MeV}/c^2$

- Masses between **Belle** and **BaBar** in good agreement
- 2.5σ away from the X(3872) world average!
- If X(3872), $J^P = 2^+$ disfavored

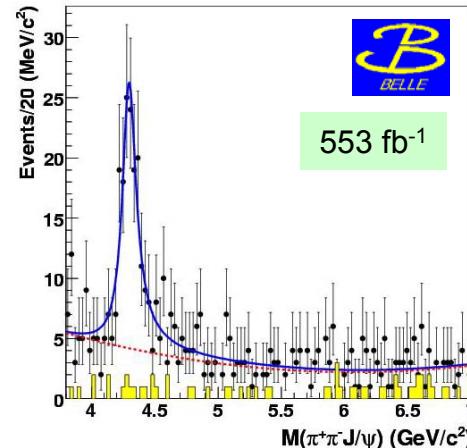
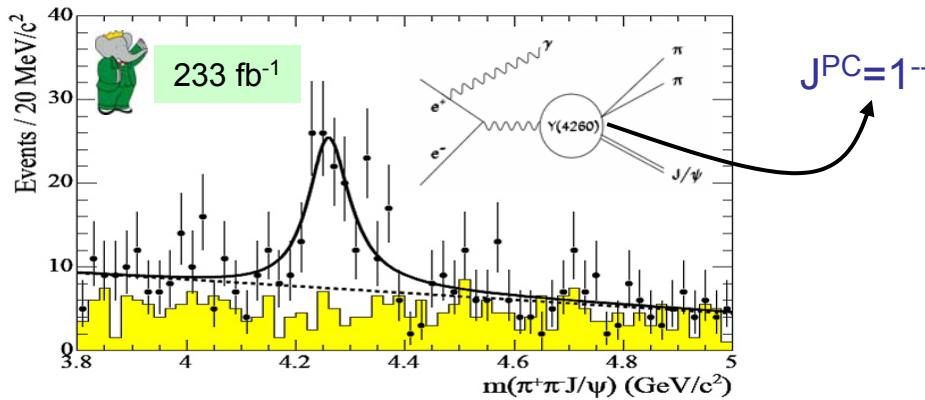
hep-ex/0606055

X(3872): INTERPRETATION

- X(3872) likely not a charmonium state
 - Radial excitation of χ_{c1} ($J^{PC} = 1^{++}$) expected at 3950 MeV/c²
 - No satisfactory c⁻c assignment
- $\bar{D}^0 D^{*0}$ molecule?
 - Phys. Rev. D71 (2005) 074005
 - $B^0 \rightarrow X(3872) K^0$ suppressed by a factor 10 compared to $B^+ \rightarrow X(3872) K^+$
 - Measurements:
 - $R(B^0/B^+) = 0.50 \pm 0.30 \pm 0.05$ in $B \rightarrow J/\psi \pi^+ \pi^-$ BaBar: Phys. Rev. D73 (2006) 011101
 - $R(B^0/B^+) = 2.23 \pm 0.93 \pm 0.55$ in $B \rightarrow \bar{D}^0 D^{*0} K$ BaBar: Preliminary
- 4 quark state?
 - Phys. Rev. D71 (2005) 014028
 - Predict 2 neutral states and 2 charged states
 - Neutral states produced in B^0 and B^+ decays: $\Delta m \approx (7 \pm 2)$ MeV/c²
 - Measurements:
 - $\Delta m = (2.7 \pm 1.3 \pm 0.2)$ MeV/c² in $B \rightarrow J/\psi \pi^+ \pi^-$ BaBar: Phys. Rev. D73 (2006) 011101
 - $\Delta m = (0.2 \pm 1.6)$ MeV/c² in $B \rightarrow \bar{D}^0 D^{*0} K$ BaBar: Preliminary
- Glueball? Hybrid? ...

Y(4260): ANOTHER MYSTERY

- New resonance discovered in $e^+e^- \rightarrow \gamma_{ISR}(J/\psi\pi^+\pi^-)$ by BaBar



- BaBar measures: $M = (4259 \pm 8) \text{ MeV}/c^2$, $\Gamma = (88 \pm 23) \text{ MeV}$
- Belle measures: $M = (4295 \pm 10^{+10}_{-3}) \text{ MeV}/c^2$, $\Gamma = (133^{+26}_{-22}{}^{+13}_{-6}) \text{ MeV}$
- Confirmed by CLEO: $M = (4283^{+17}_{-16} \pm 4) \text{ MeV}/c^2$
- No evidence for:
 - $e^+e^- \rightarrow \gamma_{ISR}(D\bar{D})$, $e^+e^- \rightarrow \gamma_{ISR}(\phi\pi^+\pi^-)$, $e^+e^- \rightarrow \gamma_{ISR}(p\bar{p})$, $e^+e^- \rightarrow \gamma_{ISR}(J/\psi\gamma\gamma)$
- 3 σ enhancement in B decays
 - $B^- \rightarrow Y K^-$, $Y \rightarrow J/\psi\pi^+\pi^-$
 - Needs confirmation

BaBar: Phys. Rev. Lett. 95 (2005) 142001

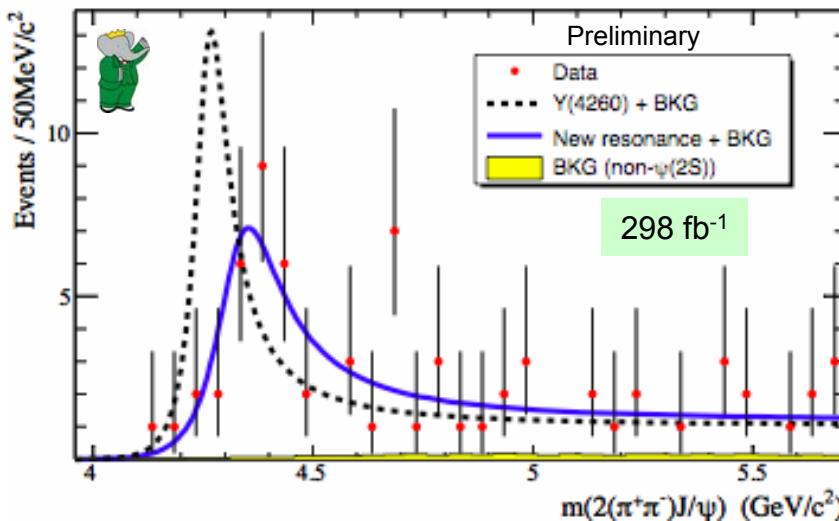
Belle: hep-ex/0612006

BaBar: hep-ex/0607083

BaBar: PRD 73, 011101 (2006)

Y(4260)... AND Y(4325)?

- Study of $Y(4260) \rightarrow \psi(2S)\pi^+\pi^-$ in ISR production



$$M = (4324 \pm 24) \text{ MeV}/c^2$$
$$\Gamma = (172 \pm 33) \text{ MeV}$$

- Incompatible
 - with BaBar $Y(4260)$, $\psi(4415)$ or 3-body phase space
- Compatible
 - with Belle $Y(“4295”)$

Y(4260): INTERPRETATION

- No $c\bar{c}$ assignment for 1^- state
- Probably not a glueball
 - No evidence for $Y(4260) \rightarrow \phi\pi\pi$
- 4 quark state $[cs][\bar{c}\bar{s}]$?
 - Should decay dominantly to $\bar{D}_s D_s$
- Hybrid meson?
 - $\bar{D}D$, \bar{D}^*D^* , $\bar{D}D^*$ decays suppressed
 - $\bar{D}D_1(2420)$ decays should dominate
- $\omega\chi_{c1}$ molecule?
 - Phys. Lett. B634 (2006) 399
- hybrid + quenched lattice QCD predicts, for 1^-
 - $M = 4380 \pm 150 \text{ MeV}/c^2$
 - Phys. Rev. D74 (2006) 034502

CONCLUSIONS

- Almost no new resonant states in more than 20 years
- Tens of them since 1999, beginning of Belle and BaBar!
- $c\bar{s}$ summary:
 - $D_{s0}^*(2317)$, $D_{s1}(2460)$: well determined experimentally, not theoretically
 - $D_{sJ}^*(2860)$, $D_{sJ}(2700)$: still unclear experimentally and theoretically
- $c\bar{c}$ summary:
 - Possibly **charmonium** states
 - $X(3940) = \eta_c(3S)$? $Y(3940) = \chi'_{c1}$? $Z(3930) = \chi'_{c2}$?
 - Probably **NOT** charmonium states (what are they?)
 - $X(3872)$, $Y(4260)$, $Y("4325")$

Experimental status:

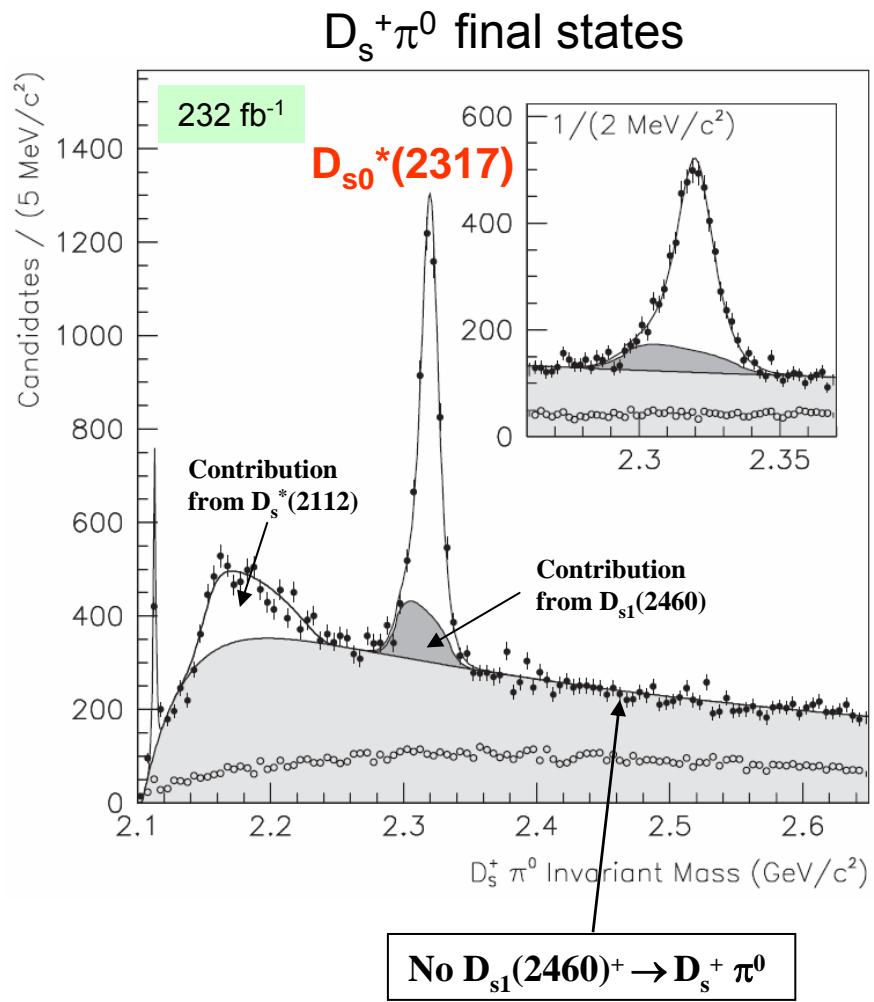
- Lots of on-going analyses with the current dataset
 - More **decay modes** investigated to understand these resonances
- Belle and BaBar are taking data till end of 2008
- Lots of new data to analyse!
 - We can bet that more **surprises** will arise!

ADDITIONAL SLIDES

$D_{s0}^*(2317)$ IN INCLUSIVE DATA



- Study of $e^+e^- \rightarrow c\bar{c}$ events
 - Resonance in $D_s^+\pi^0$
- Complex kinematics with competing contributions and mutual cross-feed
- Properties
 - $M = (2319.6 \pm 0.2 \pm 1.4) \text{ MeV}/c^2$
 - $\Gamma < 3.8 \text{ MeV}$ at 95% CL
- No decay to $D_s^+\pi^+$ or $D_s^+\pi^-$
 - No indication of isospin partners
 - 4 quark model disfavored

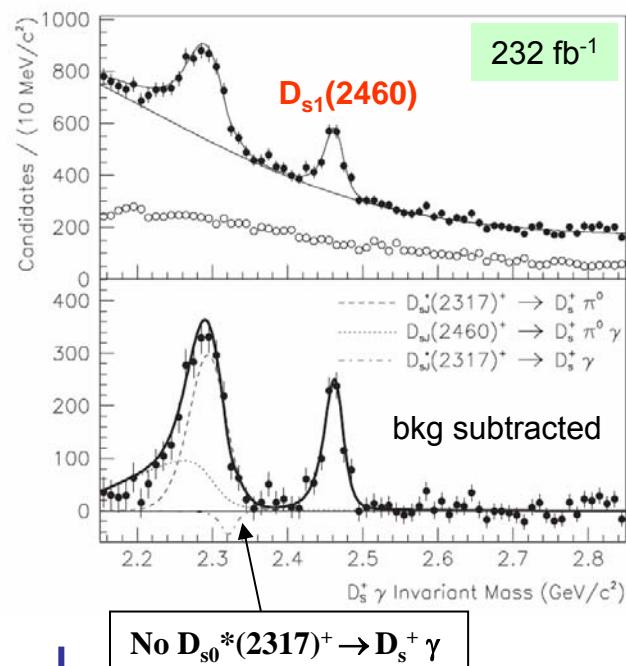




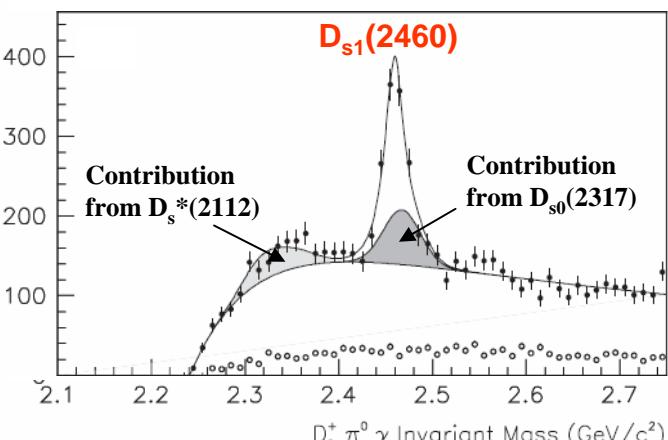
D_{s1}(2460) IN INCLUSIVE DATA

- D_{s1}(2460) observed in 3 decay final states

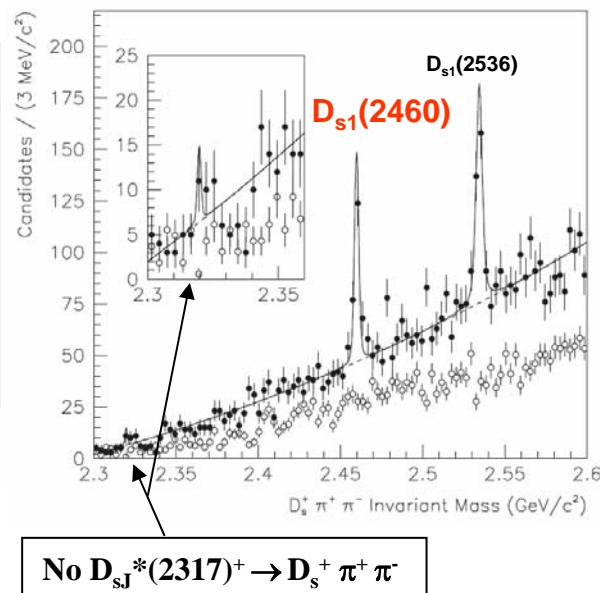
D_s⁺ γ final states



D_s⁺ π⁰ γ final states



D_s⁺ π⁺ π⁻ final states



• Properties

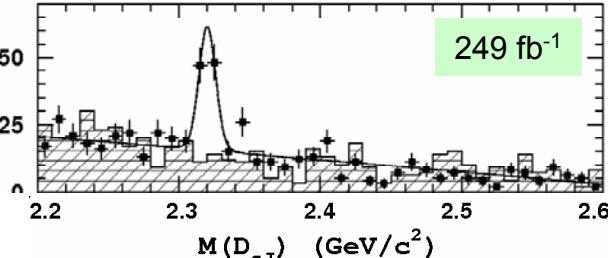
- M = (2460.1 ± 0.2 ± 0.8) MeV/c²
- Γ < 3.5 MeV at 95% CL

J^P OF $D_{s0}^*(2317)$ AND $D_{s1}(2460)$

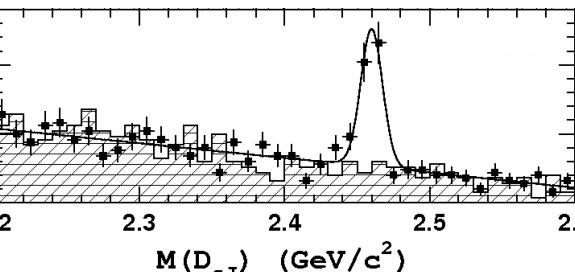


- D_{sJ} in B decays: $B \rightarrow D_{sJ}^+ \bar{D}^{(*)}$

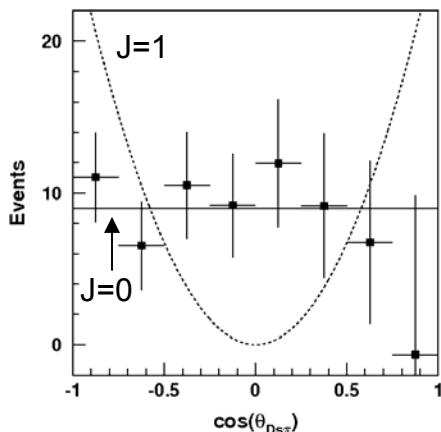
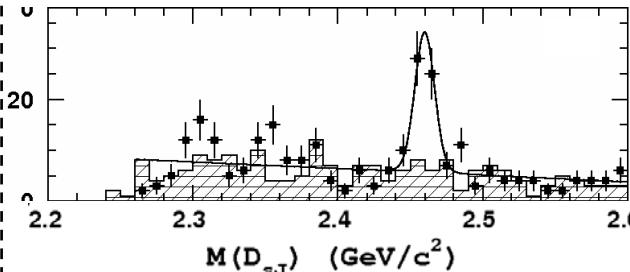
$$D_{s0}^*(2317)^+ \rightarrow D_s^+ \pi^0$$



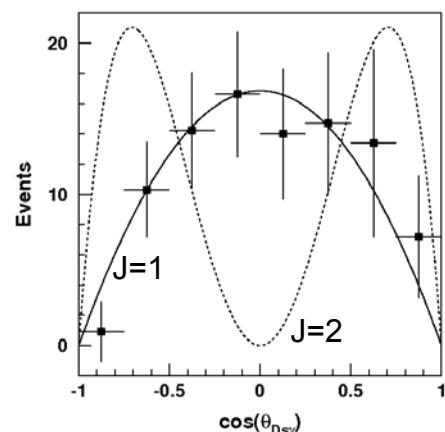
$$D_{s1}(2460)^+ \rightarrow D_s^+ \gamma$$



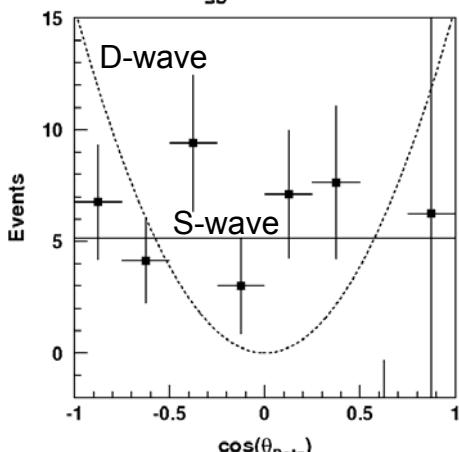
$$D_{s1}(2460)^+ \rightarrow D_s^{*+} \pi^0$$



$$J^P \Rightarrow 0^+$$



$$J \Rightarrow 1$$



$$J^P 1^- \text{ excluded}$$

$$J^P \Rightarrow 1^+$$

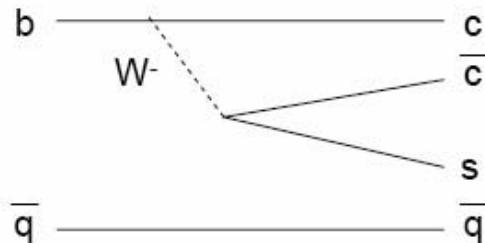
- Natural J^P : 0^+ for $D_{s0}^*(2317)$ and 1^+ for $D_{s1}(2460)$
- Confirmed by pattern of decay modes

B-Factories: production processes

Production in continuum $s^{1/2} \leq 10.58$ GeV

- Two photons production
- Double charmonium production
- Initial State radiation

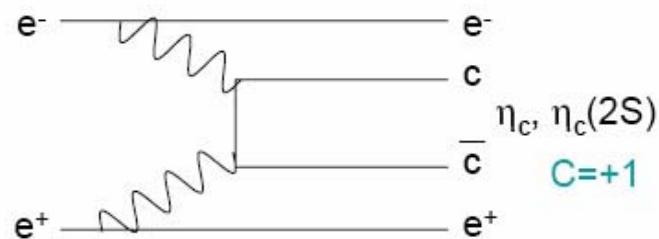
Color suppressed B decays



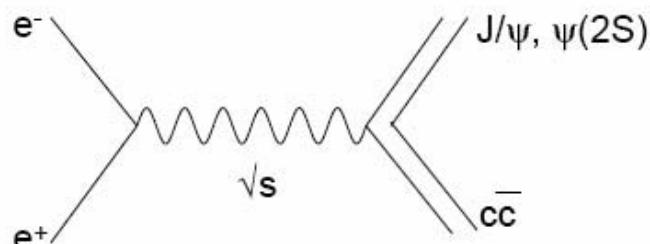
Production in B decay $s^{1/2} \approx 5.28$ GeV

$b \rightarrow c$ color suppressed transition
charmonium and open-charm

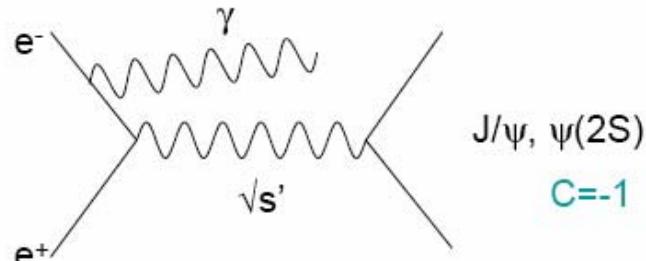
Two photons production



Double charmonium production



Initial state radiation



Y(4260): OTHER CHANNELS

- No evidence for:
 - $e^+e^- \rightarrow \gamma_{\text{ISR}}(D\bar{D})$
 - $e^+e^- \rightarrow \gamma_{\text{ISR}}(\phi\pi^+\pi^-)$
 - $e^+e^- \rightarrow \gamma_{\text{ISR}}(p\bar{p})$
 - $e^+e^- \rightarrow \gamma_{\text{ISR}}(J/\psi\gamma\gamma)$
- 3 σ enhancement in B decays
 - $B^- \rightarrow Y K^-$, $Y \rightarrow J/\psi\pi^+\pi^-$
 - Needs confirmation

